Cognitive
Engineering
Laboratory

DURESS II User's Manual: A Thermal-hydraulic Process Simulator for Research and Teaching

Lisa C. Orchanian, Thomas P. Smahel, Dianne E. Howie, & Kim J. Vicente

CEL 96-05

Cognitive Engineering Laboratory University of Toronto Department of Mechanical & Industrial Engineering
5 King's College Rd. Toronto, Ontario, Canada M5S 3G8
Phone: (416) 978-7399 Fax: (416) 978-3453
Email: benfica@mie.utoronto.ca URL: http://www.ie.utoronto.ca/IE/HF/CEL/homepage.html

Cognitive Engineering Laboratory

Director: Kim J. Vicente, B.A.Sc., M.S., Ph.D.

The Cognitive Engineering Laboratory (CEL) at the University of Toronto (U of T) is located in the Department of Mechanical & Industrial Engineering, and is one of three laboratories that comprise the U of T Human Factors Research Group. CEL began in 1992 and is primarily concerned with conducting basic and applied research on how to introduce information technology into complex work environments, with a particular emphasis on power plant control rooms. Professor Vicente's areas of expertise include advanced interface design principles, the study of expertise, and cognitive work analysis. Thus, the general mission of CEL is to conduct principled investigations of the impact of information technology on human work so as to develop research findings that are both relevant and useful to industries in which such issues arise.

Current CEL Research Topics

CEL has been funded by Atomic Energy Control Board of Canada, AECL Research, Alias|Wavefront, Asea Brown Boveri Corporate Research - Heidelberg, Defense and Civil Institute for Environmental Medicine, Japan Atomic Energy Research Institute, Natural Sciences and Engineering Research Council of Canada, Rotoflex International, and Westinghouse Science & Technology Center. CEL also has collaborations and close contacts with the Mitsubishi Heavy Industries and Toshiba Nuclear Energy Laboratory. Current CEL projects include:

- Studying the interaction between interface design and adaptation in process control systems.
- Understanding control strategy differences between people of various levels of expertise within the context of process control systems.
- Developing a better understanding of the design process so that human factors guidance can be presented in a way that will be effectively used by designers.
- Designing novel computer interfaces to display the status of aircraft engineering systems.
- Developing and evaluating advanced user interfaces (in particular, transparent UI tools) for 3-D modelling, animation and painting systems.

CEL Technical Reports

For more information about CEL, CEL technical reports, or graduate school at the University of Toronto, please contact Dr. Kim J. Vicente at the address printed on the front of this technical report.

Abstract

This manual is a stand-alone document that guides the user through the DURESS II software package. DURESS II is a thermal-hydraulic simulator which can be used for research and teaching. This document describes in detail the architecture of DURESS II, which is a bird's eye view of the entire system, and then looks at each of the various sections individually. The system is split into four separate sections: Process Model, Interfaces, Configuration Files, and Analysis Tools. The Process Model section names and describes each component of the simulator. The Interfaces section explains the three interfaces included in the software package. The Configuration Files section describes how the simulator's parameters can be customized to suit the needs of the user. The Analysis Tools section describes some of the applications that can be used to analyze the data collected from the trials. The final section is the How to section which gives step by step instructions with examples on everything from installing the software, to running a trial, to using the various analysis tools.

Table of Contents

PREFACE 1

ARCHITECTURE 1

PROCESS MODEL 2

SOURCE OF WATER 3
FEEDWATER STREAMS 4
PIPING 4
VALVES 4
PUMPS 4
HEATERS 4
RESERVOIRS 5
DEMAND 5

INTERFACES 5

PHYSICAL INTERFACE 5
PHYSICAL + FUNCTIONAL INTERFACE 7
MULTI-LEVEL INTERFACE 9

CONFIGURATION FILES 12

ANALYSIS TOOLS 13

LOG FILES 14
DPLAYER 14
DXTRACT 14
DGRAPH & DGRAPHGEN 14
DLOGGEN 15

HOW TO 15

SET UP DURESS II 15
CREATE A CONFIGURATION FILE 16
RUN A TRIAL 16
RUN DPLAYER 17
Discrete Steps *17*
Continuous Replay *18*
RUN DXTRACT 19
RUN DGRAPH & DGRAPHGEN 21
Run dloggen *21*

REFERENCES 22

APPENDICES 23

APPENDIX A: SAMPLE CONFIGURATION FILE 23
APPENDIX B: DXTRACT VARIABLES 28
APPENDIX C: SAMPLE ACTION-TRANSITION GRAPH 29
APPENDIX D: DXTRACT LOG FILE EXTRACTION PROGRAM 29
APPENDIX E: LIST OF COMMANDS 30

Table of Figures

FIGURE 1. THE ARCHITECTURE OF THE DURESS II SOFTWARE PACKAGE. 1
FIGURE 2. DIAGRAM OF DURESS II. 3
FIGURE 3. PHYSICAL INTERFACE FOR DURESS II. 5
FIGURE 4. PHYSICAL + FUNCTIONAL INTERFACE FOR DURESS II. 7
FIGURE 5A. SETTINGS LEVEL. 9
FIGURE 5B. FLOWS LEVEL 9
FIGURE 5C. PRINCIPLES LEVEL. 10
FIGURE 5D. GOALS LEVEL. 10
FIGURE 6. A SCORE BOX DISPLAYED BY DPLAYER'S 'INFO' BUTTON. 19

Preface

This technical report is a user's manual for DURESS II (DUal REservoir System Simulation), a thermal hydraulic process simulator for research and teaching. Because of it's simplicity, the system can be customized to fit a broad spectrum of needs and uses. For example, DURESS II can be used to investigate cognitive abilities, or teach students about thermal-hydraulic processes.

This report will serve as a stand-alone guide for installing and operating the DURESS II software. However, a basic understanding of UNIX commands for file management is recommended.

Architecture

Figure 1 illustrates the components of the DURESS II software package and the flow of information within this system. There are four main components; Input, Simulator, Output, and Analysis.

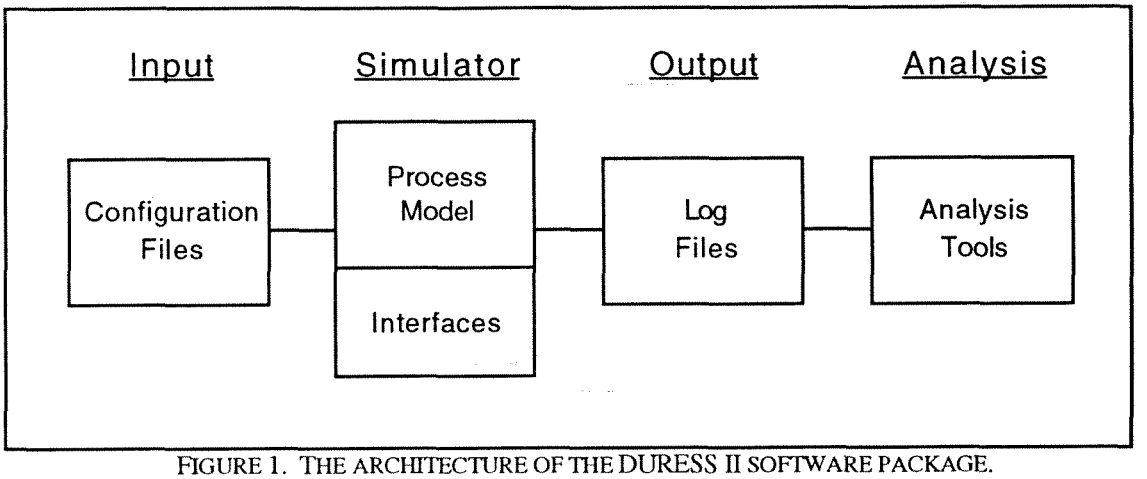


FIGURE 1. THE ARCHITECTURE OF THE DURESS II SOFTWARE PACKAGE.

In the Input segment, where the configuration files are located, one can alter the parameters of the system such as the size of the reservoirs, the amount of flow allowed through the valves, the output demands, as well as numerous other variables. In addition, pre-defined faults can be introduced into the system. These options are particularly useful because one can customize the system to suit a wide variety of needs.

The next section is the Simulator, which encompasses both the Process Model and the Interfaces. The Process Model is the heart of the system and contains the central

workings of the system -- the equations. The equations represent the characteristics of, and the relationships between, the components. As a result, they generate the behaviour of the system over time. The interfaces give the user a visual interpretation of the behaviour of the system, and the means to manipulate the components of the system in order to bring the system into a steady state. Several interface designs are included in the software package, but additional interfaces compatible with the Process Model can be created depending upon the interests of the user of the package.

After a trial has been completed, all the quantitative data describing the state of the system and the operator's control actions are retained and stored in a log file. Subsequently, these data can be accessed to compile statistics or review results specific to the trial. However, one of the tools described in the following section must be employed in order to access the data.

To view the data stored in the log files, one or more Analysis Tools can be used. The log files may be analyzed individually, selectively, or as a group to compare results. Results may be viewed in the form of graphs, tables, or even replayed back through the simulator.

Process Model

DURESS II, pictured in Figure 2, consists of two redundant feedwater streams (FWS A and FWS B) that can be configured to supply water to two reservoirs (Reservoir 1 and Reservoir 2). The goals of the system are to keep each of the reservoirs at specific temperatures, and to maintain enough water in each reservoir to satisfy each of the current output demand flow rates (D1 and D2). Both temperature and demand requirements are externally determined. Although DURESS II has been modeled to be consistent with the laws of physics (e.g., the conservation laws), several simplifying assumptions have been made, as outlined in the following sections. To satisfy the system goals, there are eight valves, two pumps, and two heaters; these all have first-order lag dynamics.

Each component code begins with the first letter of the component name: "**H**" for **h**eaters, "**V**" for **v**alves, "**P**" for **p**umps, and "**R**" for **r**eservoirs. As mentioned in the preceding paragraph, DURESS II has 2 feedwater streams: FWS **A** and FWS **B**. These letters are used in the component code to describe components in each of the respective FWS's. For example, valves in FWS A are labeled with the prefix "**VA**". The final digit in some of the component codes refers to the reservoir that the component is directly connected to. For example, the valves connected to reservoir 1 are named "**VA1** and **VB1**

and V01". Similar naming conventions are used for all of the other components of DURESS II.

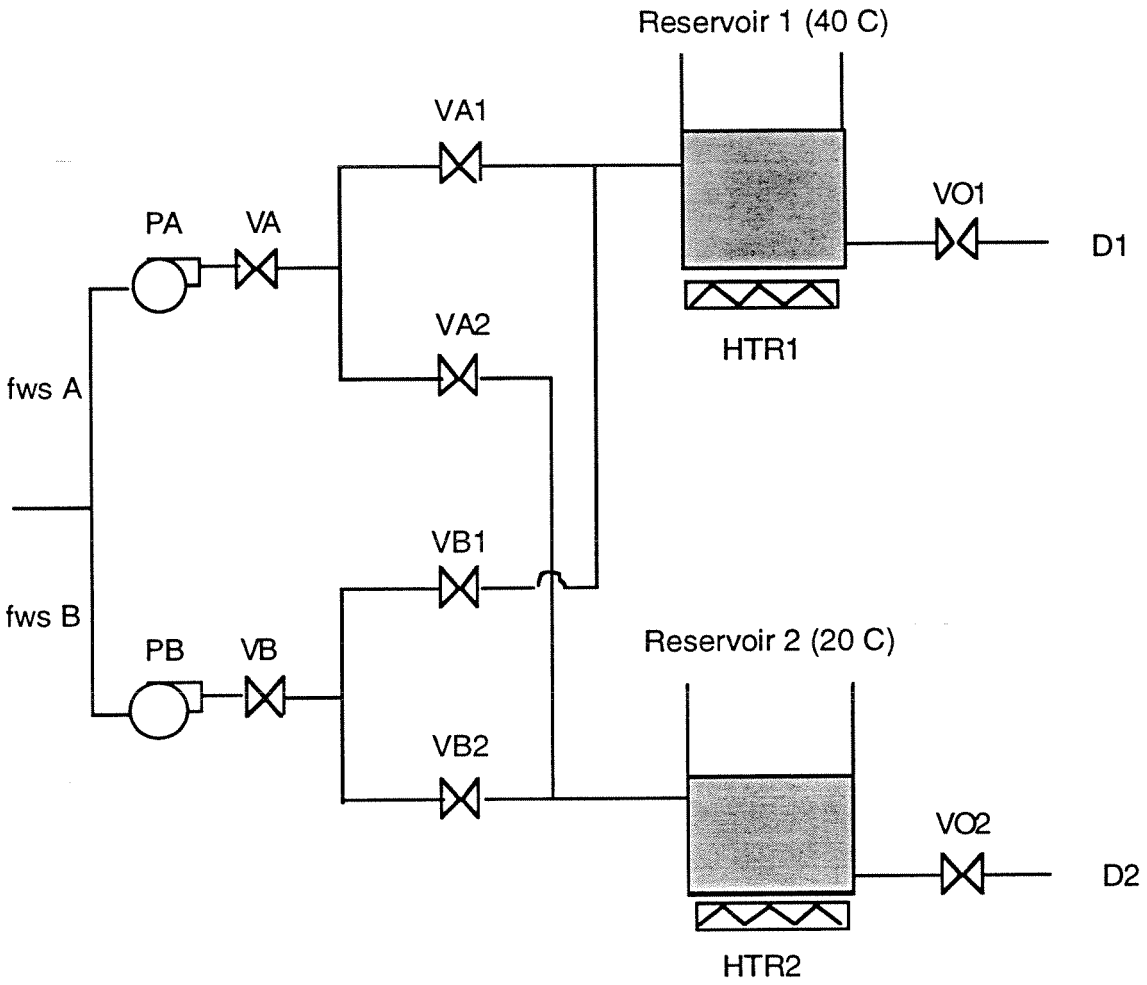


FIGURE 2. DIAGRAM OF DURESS II.

Source of Water

As shown in Figure 2, the water that feeds into DURESS II is obtained from an unlimited external source that supplies a net positive suction head. Thus, there is always water available.

Feedwater Streams

Each input feedwater stream (FWS A and FWS B) consists of one pump (PA, PB) and three valves (VA, VA1, and VA2; VB, VB1, and VB2). The two streams are functionally identical, each having a capacity for attaining a preset maximum flowrate. Each feedwater stream can be configured to supply water to both, either, or neither of the two reservoirs.

Piping

The pipes are assumed to be perfectly insulated. Thus, there will be no transfer of heat between the water in the pipes and the surrounding environment. It is assumed that the pipes are sufficiently large in diameter that their pressure losses are much smaller than those caused by the valves. Therefore, the resistance of the pipes is ignored. Note also that the length of the pipes from each of the end valves (VA1, VA2, VB1, VB2) to each reservoir is the same.

Valves

All of the eight valves are identical (VA, VA1, VA2, VB, VB1, VB2, VO1, and VO2). The valve settings have a linear range and can be varied from completely closed to all the way open. It is assumed that the valve settings directly specify the flowrates (or the flowrate ratios when appropriate) rather than the flow resistances.

Pumps

The 2 pumps (PA and PB) are functionally identical. They each have discrete settings, either ON or OFF. Each pump has a fixed maximum flowrate capacity.

Heaters

The 2 heaters (HTR1 and HTR2) are also functionally identical. They have a continuous control settings ranging from off to a maximum heat flow.

Reservoirs

The size of the 2 reservoirs can be varied independently of one another. It is assumed that the reservoirs are perfectly insulated and as a result, there is no heat transfer between the water in the reservoirs and the surrounding environment.

Demand

The demand (D1, D2) is the desired output flowrate for each reservoir. The dynamics associated with a pressure head in the reservoir (i.e., the force of gravity on the water) are not considered. Furthermore, the demands for the two reservoirs need not be the same, and can change from trial to trial or within a trial. The demand for each reservoir can range from no demand to full demand.

Interfaces

Physical Interface

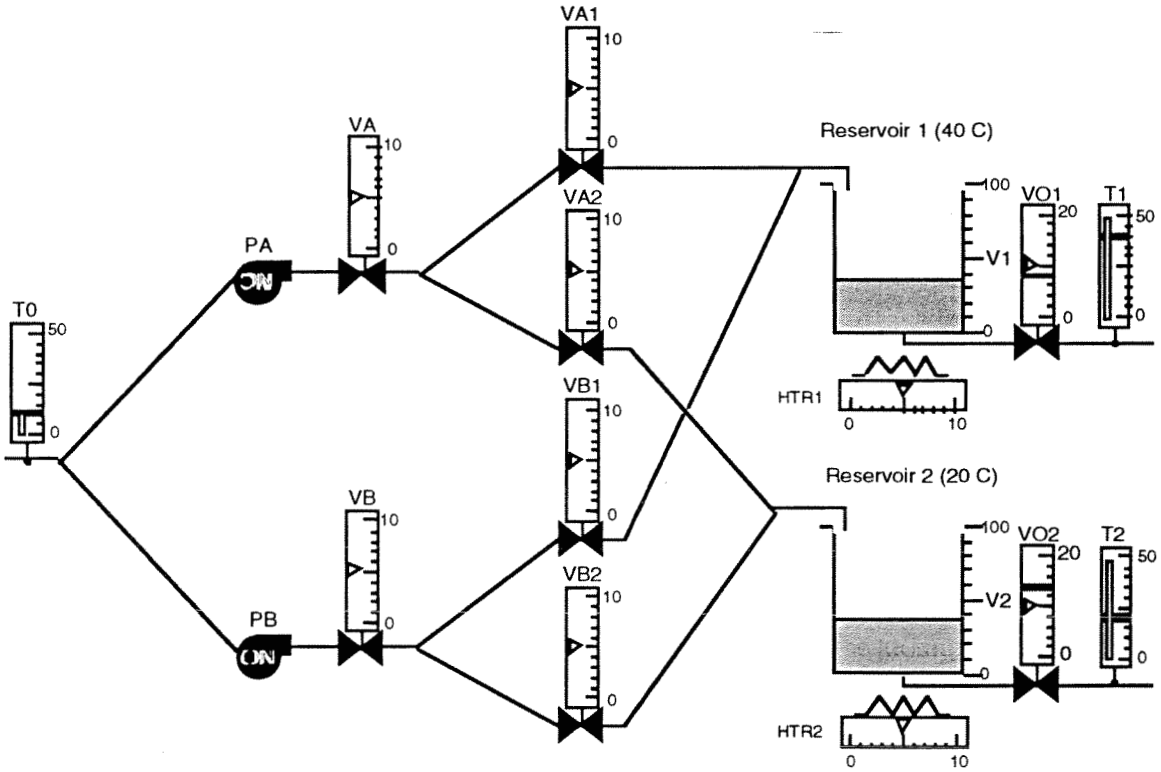


FIGURE 3. PHYSICAL INTERFACE FOR DURESS II.

The physical interface, shown in Figure 3, provides a physical representation of DURESS II, displaying only the control variables and the goal variables. (Note that for the above diagram, a set of values has been chosen for the valve capacities, and temperature and volume demands. As described later, these values can all be altered by editing the configuration file.) The first meter on the left of the display is a water thermometer (T0), which measures the temperature of the water entering the system. This thermometer displays temperature as a vertical bar (coloured red in the display) that increases in height as the water temperature increases. The normal inlet water temperature is indicated by the green area on the scale. After the thermometer, the input water stream splits and flows to two pumps (PA and PB). The pumps have discrete switches and are either on or off. The state of the pump can be changed by clicking on the pump. The pumps are displayed in black (with white lettering) if they are off, and in light gray (with black lettering) if they are on. If either pump is turned on without any of the downstream valves being opened, the pump will break down. This error terminates the trial.

The next set of components are the primary valves (VA and VB) which have a continuous range from shut to all the way open. The valve state is set using a mouse to either drag the yellow triangular pointer to the desired setting, or to simply click on the scale at the desired point. From these primary valves, each FWS splits into two secondary valves connecting each stream to both reservoirs. The secondary valves (VA1, VA2, VB1, and VB2) operate in the same manner as the primary valves. The water then flows to each of the two reservoirs, where it is heated and removed, through the use of the heaters (H1 and H2) and the output valves (VO1 and VO2), in order to meet the temperature and demand goals, respectively. Reservoir volume levels are indicated by a scale on the side of each reservoir and by the blue shaded area. It is possible to overflow either of the reservoirs, if input flowrate is consistently greater than output flowrate. When reservoir volume exceeds the maximum capacity, the trial ends automatically.

The heaters (H1 and H2) also have a continuous range from off to maximum heat flow. The subject can either slide the triangular pointer (coloured red in the display) to the desired setpoint, or click on the scale at that point. Heating an empty reservoir for an extended period will also lead to a premature end of the trial.

The water temperature in the reservoirs is displayed with thermometers (T1 and T2). The goal temperature is represented as a green area on the temperature scale. If the water in the reservoir boils, the system fails and the trial ends.

Finally, the operators also have control over the outlet valves (VO1 and VO2) that are used to meet the demand goals. These valves operate in the same manner as the other

valves. The demand for each reservoir is indicated by a green area on the valve setting scale.

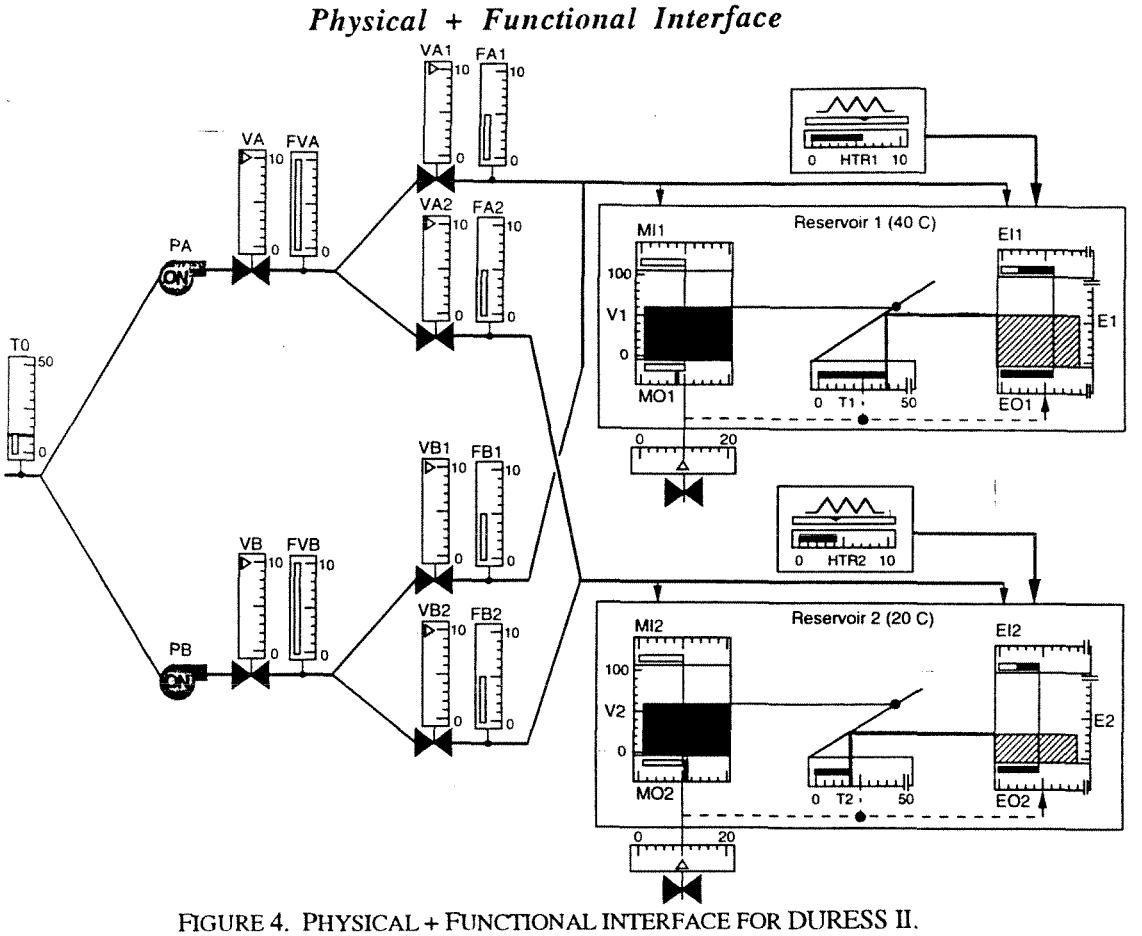


FIGURE 4. PHYSICAL + FUNCTIONAL INTERFACE FOR DURESS II.

The P+F interface, shown in Figure 4, is based on the principles of Ecological Interface Design. (For a detailed explanation of how this interface was designed, see Vicente & Rasmussen, 1990.) Again, as in the previous interface diagram, all labeled values have been arbitrarily chosen. The input water thermometer, both pumps, and all the valves operate in the same manner as in the P interface. However, the P+F interface also contains higher-order functional information that was identified through an abstraction hierarchy analysis of DURESS (see Vicente & Rasmussen, 1990). Thus, each valve also has a flow meter next to it (FVA, FVB, FA1, FA2, FB1, FB2, and MO1 and MO2 for the mass output flowrates). These flow meters have the same value range as their respective valves. The vertical bar in each meter is coloured yellow, which is the colour used throughout the interface to indicate both valve settings and flowrate values.

The group of graphics on the right of Figure 4 provide additional higher-order functional information in the form of first principles (i.e., mass and energy conservation laws). The rectangular graphic on the left represents the mass balance (i.e., input flowrate, inventory, and output flowrate) for the reservoir, and the graphic on the right represents the energy balance. Both representations operate in a similar manner. Referring to Reservoir 1, the various inputs are shown at the top (MI1 for mass and EI1 for energy). Inventories for each representation are indicated by scales on the side of each graphic (V1 for volume/ mass and E1 for energy). The outputs, MO1 for mass and EO1 for energy, are shown at the bottom of each graphic. The energy inputs (EI1 and EI2) are partialled out according to the two contributors. Thus, the energy added by the FWS is shown as the lightly shaded bar (coloured yellow in the display), and the energy added by the heater is shown as a dark red bar. The energy inventory representation in the interface is coloured orange, while the mass inventory representation is coloured blue. Intuitively, the mass and energy graphics rely on a funnel metaphor. For example, if the bottom is wider than the top (i.e., output > input), as is the case with the mass balance for Reservoir 2 in Figure 4, then it is easy to visualize the consequence; namely, that volume should decrease. Thus, the slope of the line represents the rate at which the mass (or energy) inventory should be changing. If input equals output, then the line is perpendicular, indicating that the level should not be changing.

The graphic in the middle, between the mass and energy balances, illustrates the relationship between mass, energy, and temperature. The horizontal line with a ball on the end that emanates from the current mass inventory level is coloured light blue in the display. Changes in the height of this line always accompany any change in mass inventory (i.e., the bar will always be at the same height as the water level, V1 or V2). The diagonal line in the center display is always tangent to the ball on the end of that horizontal line. Thus, a change in the vertical position of the horizontal line serves to change the slope of the diagonal line in the center display. For example, if volume increases, the horizontal line goes up, causing the diagonal to rotate counterclockwise, increasing the slope of the diagonal line. The slope of the diagonal line represents the function that maps the relationship between mass and energy onto temperature. This mapping is indicated by the line emanating from the current energy inventory level (E1 and E2) that comes across and reflects off of the diagonal line and down onto the temperature scale (T1 and T2). The goal temperature is indicated by the light shaded area (coloured green in the display). This goal area reflects back from the temperature scale, off of the diagonal line, and onto the energy scale. In addition, off-scale markers are added to the output temperature scales and the

energy input, inventory, and output scales as well. This was added to the system by creating a gap in the scale at the off-scale point.

Multi-Level Interface

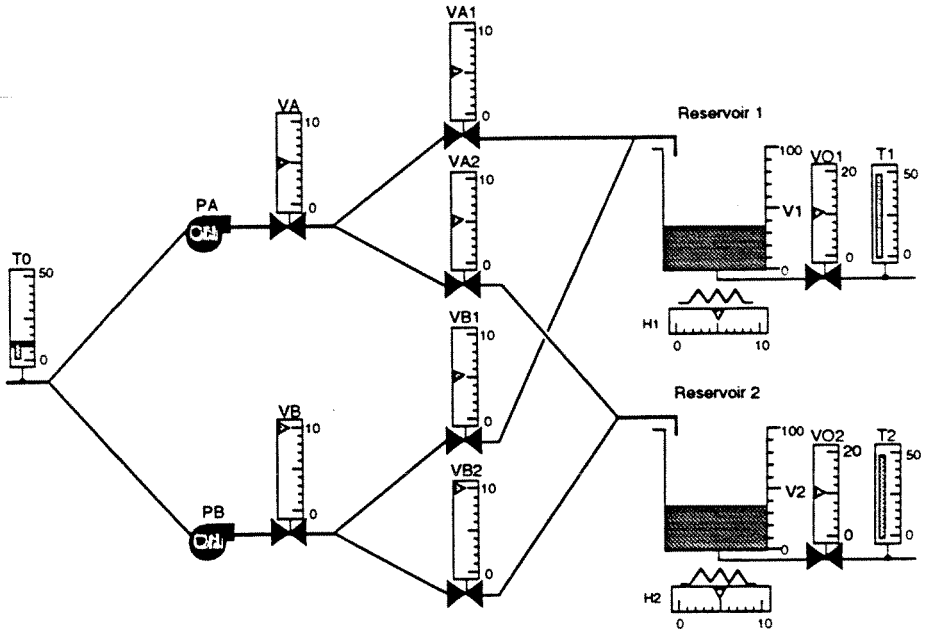


FIGURE 5A. SETTINGS LEVEL

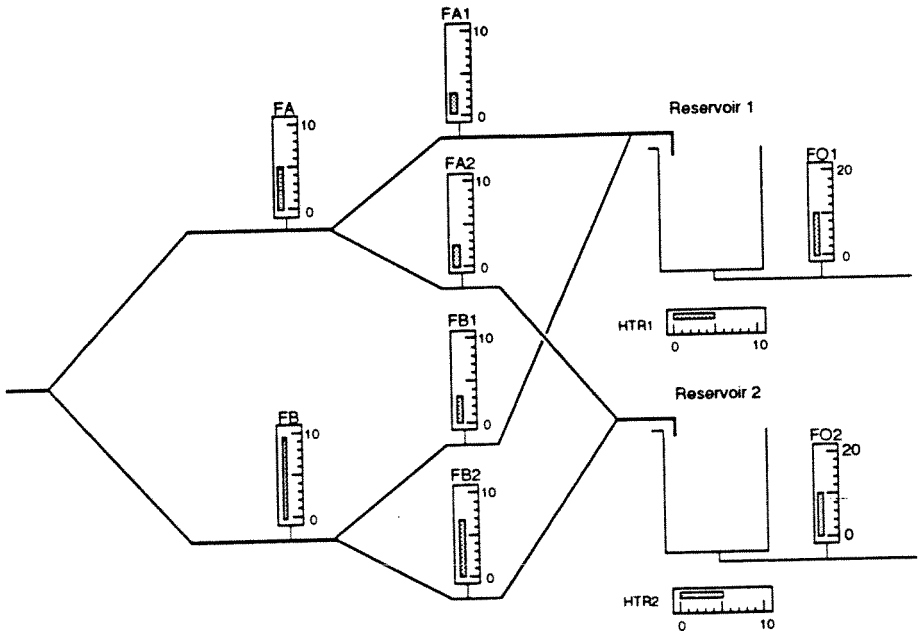


FIGURE 5B. FLOWS LEVEL

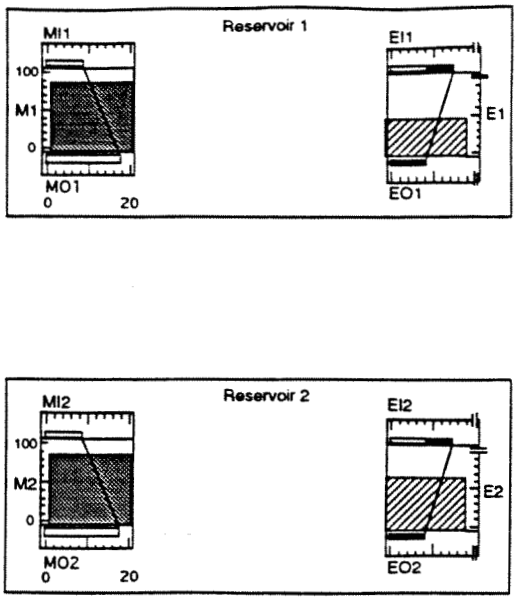


FIGURE 5C. PRINCIPLES LEVEL

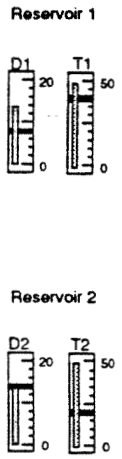


FIGURE 5D. GOALS LEVEL

There are four levels to this interface; Settings, Flows, Principles, and Goals. Only one of the four levels can be viewed at any time. In the lower left hand corner of the screen is a control panel with four buttons. Any level can be accessed at any time by clicking on the corresponding button with the mouse.

The Settings level (Figure 5A) shows the controls which are used to operate the system, as well as some state information. The input water temperature is shown in

thermometer T0, on the left. The pump settings (e.g., PB) are discrete (either ON or OFF), and are therefore directly labeled on the pumps themselves. The valve settings (e.g., VB) range from 0 to a preset maximum and are indicated by the small yellow, triangular pointers on the respective scales. The blue graphic shows the reservoir volume (e.g., V1), which ranges from 0 to 100 percent. The output valve setting (e.g. VO1) is on the right and is indicated by a yellow triangle. The heater settings (e.g., HTR2) range linearly from completely off to maximum capacity, with a red triangle as an indicator. The thermometer on the right of each reservoir shows its temperature (e.g. T1).

The Flows level (Figure 5B) only shows the actual flow rate for each component, corresponding to the components from the Settings level. The flow rate for each valve ranges from 0 to maximum capacity and is indicated by a yellow bar in roughly the same location as the corresponding valve display from the Settings level. The flow rates for the output valves are shown as yellow bars on the right. The heat transfer rates for the two heaters are indicated by the red bars.

The Principles level (Figure 5C) only shows information according to the mass and energy conservation laws. The blue graphic on the left represents the mass balance for the reservoir, while the orange graphic on the right represents the energy balance. Both operate in a similar manner. Referring to Reservoir 1, the various inputs are shown at the top (e.g., MI1 for the mass input and EI1 for the energy input), the outputs at the bottom (e.g., MO1 for mass output, and EO1 for energy output) and the inventories on the side (e.g., M1 for mass, and E1 for energy). The energy inputs (EI1 and EI2) are partialled out according to the two contributors. Thus, the energy added by the feedwater is shown as the yellow bar, while the energy added by the heater is shown as the red bar. The energy output (e.g., EO1) is proportional to the product of temperature (T1) and mass output (MO1). Intuitively, the energy and mass graphics rely on a funnel metaphor. Thus, if the bottom is wider than the top (i.e., output greater than input), then it is easy to visualize the consequence, namely that the volume should be decreasing. Thus, the slope of the line represents the rate of change of mass (or energy) of inventory.

The Goals level (Figure 5D) only shows the current state of the goal-demand (D1, D2) variables with respect to the corresponding goal states. These variables are the outflow rates (yellow bars) and temperatures (T1, T2) of the reservoirs (red bars). The green areas represent the goal regions. The upper and lower limits around the setpoints are shown as green areas on the two temperature scales. The upper and lower limits around the demands, are shown as green areas on the output flowrate meters.

Configuration Files

Although the form of the basic elements of the process model remain constant, the Configuration Files allow users to alter the simulation to suit their needs. The configuration files give the users the power to directly manipulate the variables that are fed into the simulator. Examples of variables include reservoir size, individual valve capacity, heat transfer rate, and demand settings. In addition, simulated faults can be configured to occur during the trial (i.e. valve blockage, reservoir leak, heater failure, etc.) and it is possible to specify initial conditions for the trial (i.e. water initially found in the reservoir).

Even though the parameters of the simulator can take on an infinite number of values, the relationships between the elements that govern the performance of the simulator impose constraints on meaningful combinations of values. For instance, if the density of the liquid in the feedwater streams is changed to one-tenth that of water, the reservoirs would fill up so fast that the operator would have an extremely difficult time controlling the system.

Users may find the following alterations of particular interest:

Feedwater Streams:

- input temperature
- pump capacities (independently variable)
- valves (each configured with different flow capacities)
- splitters (allow limited flow from primary to secondary valves)

Reservoirs and Heaters:

- reservoir size
- maximum reservoir height
- water demand temperature
- water density
- initial water level
- maximum heat flow from heater

Faults (occurring after set period of time):

- change in demand (flow or temperature)
- additional water into/out of reservoir
- additional heat into reservoir

- valve blockage
- valve stickage
- heater failure
- change to inflow temperature
- pump failure

An example of a configuration file is provided in Appendix A. For this particular trial, the mass and temperature demands are set at 6 kg/sec and 40 °C for Reservoir 1, and 9 kg/sec and 20 °C for Reservoir 2. For the operator to reach 'steady state', these goals must be maintained for five consecutive minutes. The trial also includes two faults. The first fault is a reservoir leak which occurs in Reservoir 1 at three minutes. Once the counter reaches that time, the reservoir will start to lose water at an additional rate of 3 kg/s. This loss will not be detectable in the outflow measurement (i.e. the mass balance line will not change). However, the water level will drop for no apparent reason. The second fault occurs at four minutes. While the first fault was a loss of water, this fault results in additional water inflow to Reservoir 2. At the time of this fault, the reservoir will start to gain 3 kg/s of water at 30 °C. Also like the leak, the extra water will not be detected in the inflow measurement, but the water level will rise and possibly temperature too.

A fault can be added to any trial simply by changing the '-1' where the 'time of fault' is specified to the desired time in minutes. For instance in the example, the faults are found in the 'reservoir' sections and the '-1's have been changed to '3' and '4' accordingly. Then the 'additional water inflow' was changed to '-3' for Reservoir 1, and '3' for Reservoir 2. As well, the 'addition inflow temperature' for Reservoir 2 was changed to '30'. This combination of changes to the configuration file will create the faults described above. The maximum number of faults in a trial is 30.

Analysis Tools

In the following sections, a description of what each tool does is included. For a description on how to use the following tools, please consult the 'How To' section for the analysis tool desired. For a list of the UNIX commands associated with these analysis tools, please consult Appendix E.

Log Files

Whenever the operator clicks the mouse, the simulation records the control action, the time, and the current values of all of the system variables. These data are stored in a Log File. All of the analysis tools described below use the Log Files as input. It is important to note that the log files cannot be read directly, but rather have to be used in conjunction with another analysis tool to extract data.

dplayer

Dplayer is a trial replay module. It is a useful device for reviewing the individual trials. Dplayer can play back a trial showing the interface used by the operator while the operator's control movements are highlighted with an arrow. The trials can be interpolated to show continuous movement between control inputs. It is also possible to fast forward or rewind through the control inputs of the trial.

dxtract

Dxtract is the utility which allows the user to isolate data from the log files to be analyzed. Using dxtract, the user can extract data in its entirety or selectively. Some of the variables which can be analyzed include PA setting, VB1 flow, reservoir 2 level, reservoir 1 energy inflow from water, etc. An extensive list is included in Appendix B. Through the extraction process, it is possible to transfer the data to a file which can be used in any spreadsheet program.

dgraph & dgraphgen

Dgraph and dgraphgen are analysis tools that can be used in combination to draw action transition graphs from data extracted from the log files. Dgraphgen prepares the data to be plotted by dgraph. Action transition graphs reveal sequential relationships in behavior. Each component is represented by a node, and those nodes that are acted on in sequence are joined by a line. The thickness of a line joining any two nodes is proportional to the frequency of that transition. Action transition graphs can illustrate changes in patterns of skill, providing a summary of an individual's understanding of the system on a

trial by trial basis. (Moray, Looststeen, & Pajak, 1986) A sample action transition graph is included in Appendix C.

Dgraphgen gives the user three options for the number of nodes in the graph.

- dgraphgen 1: all 12 components
- dgraphgen 2: 6 nodes (pumps (2), primary valves (2), and heaters (2))
- dgraphgen 3: 3 nodes (all pumps, all valves, and all heaters)

dloggen

Since DURESS II is fully deterministic, log files contain only the operator's actions. In order to obtain variable values between actions, it is necessary to interpolate using the existing log file. Dloggen generates a log file containing data with a known fixed selectable interval. For example, one could retrieve the state of the trial every 15 seconds. From the newly created log file, one could analyze the data variables using dxtract.

How to ...

Set Up DURESS II

Obtaining and setting up the DURESS II software package is an easy process. It can be obtained by using a file transfer protocol:

% ftp ftp.ie.utoronto.ca
% login: anonymous
% password*: [type in your full login address]*
% cd incoming
% get duress.Nick.tar.gz

Once you have the received the file unzip it using:
% gunzip duress.Nick.tar.gz
% tar -xf duress.Nick.tar

These commands will unpack all the files and place them into their appropriate directories.

Create A Configuration File

Several sample configuration files are included in the DURESS II software package. In order to create a unique configuration file:

1. enter a text editor such as vi or jot
2. open an existing configuration file
3. make desired alterations to existing variables
4. save file under a new filename

Run A Trial

Once the DURESS II software package has been installed, simply type 'duress' at the prompt. From there a window titled 'DURESS SIMULATOR' will open.

1. Click on the ConFile box
2. Enter the directory where the configuration files are located
3. Choose the desired configuration file
4. Click on 'Ready'
5. If the trial needs to be stored for further analysis, a subject name and trial number must be entered in the appropriate boxes. Otherwise, no log file will be created. (Hint: Choose "01" rather than "1" for the first trial number to keep the log files in numerical order.)
6. To choose an interface, click repeatedly on the interface box until the desired interface is shown

The DURESS II simulator offers the option of having an on-screen timer and either a limited or unlimited simulation time. For the on-screen timer, click 'on' or 'off'. For the simulation time, click 'limited' or 'unlimited'. If the former is chosen, a time limit box will appear; enter the desired time limit there in minutes. Once the simulation has reached the

time limit, it will automatically halt the simulation. Once all the parameters are properly set, click on 'OK' and the trial will begin immediately.

Run dplayer

To use the dplayer trial replay module, type 'dplayer' at the prompt and a window titled 'Duress Player' will open.

1. Click on the Log File box and go to the directory containing the log files. Select the desired log file and click on 'Ready'. (Hint: Only uncompressed log files will be listed.)
2. Clicking repeatedly on the intermediate values box gives the option whether or not to generate intermediate values . If the intermediate values are desired, then they will be calculated by interpolating between control actions. This only applies to the continuous mode of play.
3. As well, the speed of the continuous replay can be varied by sliding the bar in the speed box anywhere between normal and fast.
4. Click on 'OK'.

The interface is configured to match the state of the system at the beginning of a trial. There is a graphic in the bottom left hand corner of the screen which contains the controls for Dplayer. Dplayer can be controlled somewhat like a tape player or VCR. It operates in two modes: discrete steps and continuous replay.

Discrete Steps

In the discrete mode, Dplayer can be controlled using two keys: the key with the blue double arrow pointing to the right (>>) and the key with the blue double arrow pointing to the left (<<). The >> key allows the user to move forward through the trial, step by step. Similarly, the << key backs up through the trial, step by step.

There is a small clock just above these keys which indicates the time that has elapsed in the trial. At the beginning, the clock reads 00:00:00. In the step by step play

mode, the clock will not advance uniformly. It displays only the times at which control actions were made.

When the >> key is pressed, the first control action is highlighted with a large green arrow. As the trial progresses by pressing the >> key, each control action in turn is highlighted by the large green arrow. It should be noted that the time intervals between each control action are **not** equal.

Another way to determine the relative position within the trial is to refer to the slider just below the timer. When the indicator is in its extreme left hand position, the trial is just beginning. When the indicator is in its extreme right hand position, the trial is at the end. At intermediate times in the trial, the indicator will show the position relative to the beginning and end of the trial. However, in the discrete steps mode of operation, Dplayer will not advance beyond the last control action even if this is not yet the end of the trial.

Continuous Replay

In the continuous replay mode, it is possible to play the trial continuously using the key with the blue single arrow pointing to the right (>). In this mode of operation, the key with the blue square pauses the trial. To resume playing the trial again, the > key will restart the continuous replay. The keys to the right of the timer control the speed of the replay. The up arrow (Δ) speeds up the rate of replay, while the down arrow (V) slows down the rate of replay.

In the continuous replay mode of operation, a message box will indicate the end of the trial and the reason for the termination (e.g., steady state was reached). Additional information from the trial can also be accessed by clicking on the 'inf.' button in the 'iDURESS Control Panel' window. The following information will be listed in the window:

- Subject
- Trial
- Date & time of trial
- Interface used
- Total time of trial
- Configuration file used
- How the trial was terminated

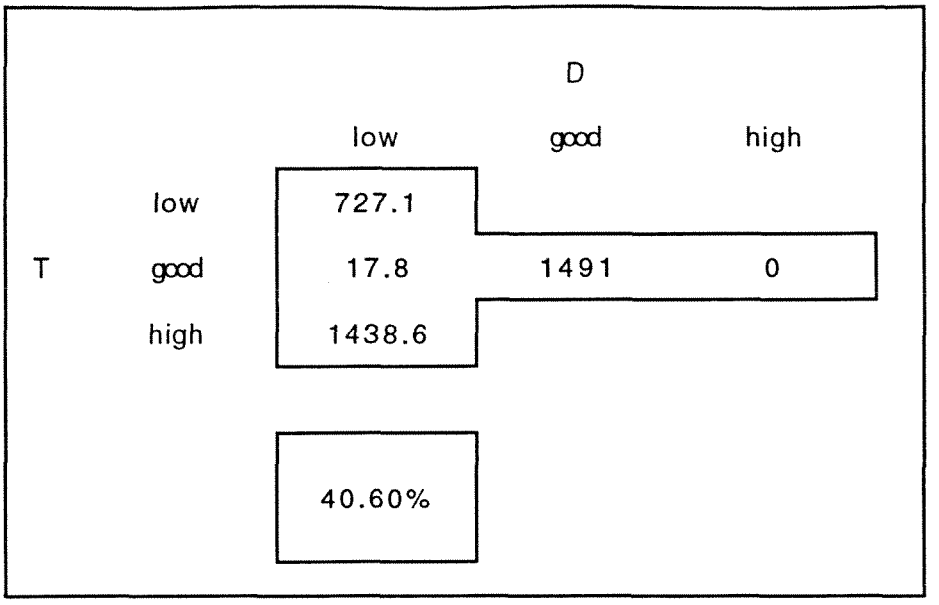


FIGURE 6. A SCORE BOX DISPLAYED BY DPLAYER'S 'INFO' BUTTON.

Furthermore, there is a score box, illustrated in Figure 5, which gives statistics on the amount of water that was released from the system, in and out of the temperature and demand goals. It also gives the percentage of water released which was completely in the goal regions. For instance, in Figure 6 the score box shows that 40.6% of the fluid that the operator released from the system that was within both temperature and demand goal regions.

Run dxtract

In order to analyze individual variables, or groups of variables, from the Log Files, dxtract can be used in a multitude of ways. For example, if the user wanted to extract the flow through valve VA from the Log File 'xx.01.log', the following commands must be executed (the % sign indicates the UNIX prompt and the system response is indented):

```
% dxtract xx.01.log > VAflow      # 'VAflow' is an arbitrary destination file
                                  # name
```

1. PA state
2. PB state
3. VA setting
4. VA flow
5. VA1 setting
....
42. Actions

Choice: 4 # Enter 4 for VA flow data

Or alternatively, if the user know's which component number they want to extract, it can be typed in directly:

% dxtract -v 4 xx.01.log > VAflow

To extract VB flow from a file called 'xx.01.log' and save it in file 'Vbflow', the following command should be typed:

% dxtract -v 10 xx.01.log > VBflow

Files created with 'dxtract' will have two columns of data separated by tabs. The first column is always 'time' and the second the extracted variable. The first row contains a header describing the data in each column.

To combine two (or more) already extracted files into one, e.g., 'VAflow' and 'VBflow' into 'flows', use:

% combine VAflow VBflow > flows

This will create the file 'flows' with three columns: time in the first, VAflow in the second, VBflow in the third. An algorithm to run dxtract for a series of log files is included in Appendix D.

Run dgraph & dgraphgen

To use dgraph, the analysis must be run from a directory where dxtract, dgraphgen, and dgraph are all accessible. Once this is done, the following commands must be typed:

```
% dxtract -v42 <logfile> > logfile.dx        # takes the 'action' data from the
                                             # desired logfile and places it in a file
                                             # called 'logfile.dx'

% cut -f1,2 logfile.dx > logfile.cut         # puts the first 2 columns from
                                             # 'logfile.dx' into a file called
                                             # 'logfile.cut'

% cat logfile.cut | dgraphgen 1 | dgraph     # sends 'logfile.cut' to dgraphgen and
                                             # using style 1 (all the components) to
                                             # dgraph which plots it on the screen
```

Once the graph has been displayed on the screen, adjustments can be made to make clarify the graph. For instance, if a node happens to be blocking a path line, the node can be moved slightly by dragging and dropping it. Also, if the subject repeatedly switched between two nodes, the path line will be very thick, thus obstructing the view of other lines. The overall thickness of the lines can be reduced using the slider in the bottom left corner of the screen. Once the graph is satisfactory, it can be saved to a file of any format by clicking on the 'Save' button.

Run dloggen

In order to use dloggen, the user must be in the same directory as the log files. Then the user must decide the time interval for the interpolation. The following command shows how to use dloggen if one desires an interval time of 10 seconds for the file called 'old.log' to be saved as 'new.log'

```
% dloggen 10 old.log new.log
```

References

Moray, N., Looststeen, P., & Pajak, J. (1986). Acquisition of process control skills. *IEEE Transactions of Systems, Mand, and Cybernetics, SMC-16,* 497-504.

Vicente, K. J. & Rasmussen J. (1990). The ecology of human-machine systems II: Mediating "direct perception" in complex work domains. *Ecological Psychology, 2,* 207-249.

Appendices

Appendix A: Sample configuration file

```
#################################################################
# Sample configuration file for DURESS II                       #
#                                                               #
# + recommended values to change are marked with #*             #
# + use -1 as the fault time when no fault needed;              #
#   all fault times are in minutes                              #
# + comments start with # and continue to the end of line       #
#                                                               #
#################################################################
#
# global values
        0.1     # simulation interval (sec)
        5       # steady time (min)
        0       # time after which steady state is checked (min)
        1.5     # temperature margin (C)
        1       # demand margin (kg/sec)

#******************** Demand change ************************
# change in demand for upper reservoir
        dc1     # the name
        20      # maximum demand (kg/sec)
        6       #* initial demand (kg/sec)
        6       #* initial demand (kg/sec)
        0.1     # time constant
        0       #* demand when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* demand when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# change in demand for lower reservoir
        dc2     # the name
        20      # maximum demand (kg/sec)
        9       #* initial demand (kg/sec)
        9       #* initial demand (kg/sec)
        0.1     # time constant
         0      #* demand when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* demand when fault 2 (0..maximum flow)
        -1      #* time of fault 2

#******************** Hidden heaters ************************
# inflow
        hh0     # the heater name
        50      #* maximum temperature (C)
        10      #* initial temperature (C)
        10      #* initial temperature (C)
        15      # time constant
         0      #* temperature when fault 1 (0..maximum flow)
```

```
        -1      #* time of fault 1
        0       #* temperature when fault 2 (0..maximum flow)
        -1      #* time of fault 2

# reservoir 1
        hh1     #  the heater name
        2.09e6 #  max heat flow to reservoir 1 (W)
        0       #  initial heat flow
        0       #  initial heat flow
        15      #  time constant
        0       #* heat flow when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* heat flow when fault 2 (0..maximum flow)
        -1      #* time of fault 2

# reservoir 2
        hh2     #  the heater name
        2.09e6 #  max heat flow to reservoir 2 (W)
        0       #  initial heat flow
        0       #  initial heat flow
        15      #  time constant
        0       #* heat flow when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* heat flow when fault 2 (0..maximum flow)
        -1      #* time of fault 2

# ******************* Upper string ***************************
# pump PA
        PA      #  the pump name
        0       #* initial state (0: off, 1: on)
        0.05    #  minimum flow through pump
        10      #  maximum flow through pump (kg/sec)
        5       #  time constant
        -1      #* time of fault
        5       #  time to blow up when valves are closed
# valve VA
        VA      #  the valve name
        10      #  maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# valve VA1
        VA1     #  the valve name
        10      #  maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
```

```
        -1      #* time of fault 2
# valve VA2
        VA2     #  the valve name
        10      #  maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# splitter
        20      #  maximum flow through splitter (kg/sec)

# ******************* Lower string ***************************
# pump PB
        PB      #  the pump name
        0       #* initial state (0, 1)
        0.05    #  minimum flow through pump
        10      #  maximum flow through pump (kg/sec)
        5       #  time constant
        -1      #* time of fault
        5       #  time to blow up
# valve VB
        VB      #  the valve name
        10      #  maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant1
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# valve VB1
        VB1     #  the valve name
        10      #  maximum flow through valve
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# valve VB2
        VB2     #  the valve name
        10      #  maximum flow through valve
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow thru valve (0..maximum flow)
        5       #  time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# splitter
```

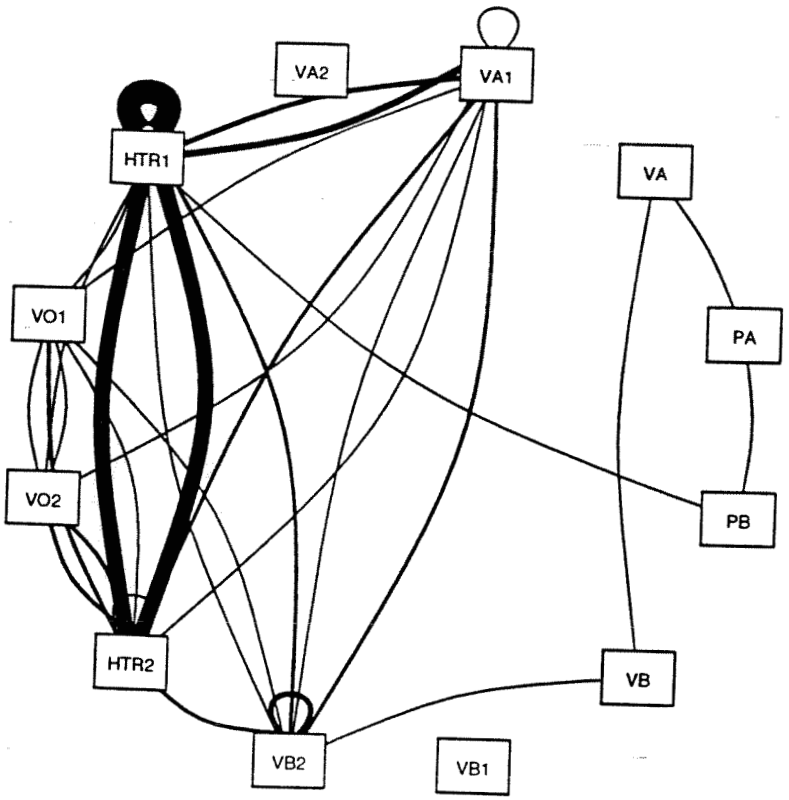
```
        20      # maximum flow through splitter (kg/sec)

# ***********************************************************
# upper heater
        10      # the maximum heater setting (0..inf)
        0       #* initial heater setting (0..maximum setting)
        0       #* initial heater output (0..maximum setting)
        1.25e6 #  maximum heat flow from heater (W)
        15      # time constant
        -1      #* time of fault
        -1      #* output percentage when fault occurs

# lower heater
        10      # the maximum heater setting (0..inf)
        0       #* initial heater setting (0..maximum setting)
        0       #* initial heater output (0..maximum setting)
        1.25e6 #  maximum heat flow from heater (W)
        15      # time constant
        -1      #* time of fault
        -1      #* percentage of fault

# ***********************************************************
# upper reservoir
Reservoir 1     # the reservoir name
        20      # maximum water inflow (kg/sec)
        20      # maximum water outflow (kg/sec)
        0       #* initial water level (m)
        0.01    # minimum water level
        1       # maximum water level
        40      #* water demand temperature (C)
        50      # maximum water temperature
        2.09e3 #  minimum energy inflow
        2.09e6 #  maximum energy inflow
        2.09e6 #  maximum energy outflow
        0       #* initial energy stored in reservoir (J)
        168e6   # maximum energy stored in reservoir
        1       # tank area (m2)
        1000    # water density (kg/m3)
        4.2e3   # specific heat capacity of water (J/kg.C)
        100     # water boiling temperature (C)

        -3      #* additional water inflow (kg/s)
                #       >0: additional inflow, <0:leak
        0       #* additional inflow temperature (C)
                #         needed when water inflow is > 0
        3       #* time of additional inflow fault
        30      # time for reservoir to blow up

# lower tank
Reservoir 2     # the reservoir name
        20      # maximum water inflow (kg/sec)
        20      # maximum water outflow (kg/sec)
        0       # initial water level (m)
        0.01    # minimum water level
```

```
        1       # maximum water level
        20      #* water demand temperature (C)
        50      # maximum water temperature
        2.09e3 # minimum energy inflow
        2.09e6 # maximum energy inflow
        2.09e6 # maximum energy outflow
        0       #* initial energy stored in reservoir (J)
        168e6  # maximum energy stored in reservoir
        1       # tank area (m2)
        1000   # water density (kg/m3)
        4.2e3  # specific heat capacity of water (J/kg.C)
        100    # water boiling temperature (C)

        3       #* additional water inflow (kg/s)
                #         >0: additional inflow, <0:leak
        30      #* additional inflow temperature (C)
                #         needed when water inflow is > 0
        4       #* time of additional inflow fault
        30      # time for reservoir to blow up

# ************************************************************
# valve VO1
        VO1     # the valve name
        20      # maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow through valve (0..maximum flow)
        5       # time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
# valve VO2
        VO2     # the valve name
        20      # maximum flow through valve (kg/sec)
        0       #* initial valve setting (0..maximum flow)
        0       #* initial flow through valve (0..maximum flow)
        5       # time constant
        0       #* valve setting when fault 1 (0..maximum flow)
        -1      #* time of fault 1
        0       #* valve setting when fault 2 (0..maximum flow)
        -1      #* time of fault 2
```

Appendix B: Dxtract Variables

1. PA state
2. PB state
3. VA setting
4. VA flow
5. VA1 setting
6. VA1 flow
7. VA2 setting
8. VA2 flow
9. VB setting
10. VB flow
11. VB1 setting
12. VB1 flow
13. VB2 setting
14. VB2 flow
15. VO1 setting
16. VO2 setting
17. HTR1 setting
18. HTR1 flow
19. HTR2 setting
20. HTR2 flow
21. Reservoir 1 water level
22. Reservoir 1 water temperature
23. Reservoir 1 water inflow
24. Reservoir 1 water outflow
25. Reservoir 1 water demand
26. Reservoir 1 energy inflow from water
27. Reservoir 1 energy inflow from heater
28. Reservoir 1 energy outflow
29. Reservoir 1 energy level
30. Reservoir 1 water target temperature
31. Reservoir 2 water level
32. Reservoir 2 water temperature
33. Reservoir 2 water inflow
34. Reservoir 2 water outflow
35. Reservoir 2 water demand
36. Reservoir 2 energy inflow from water
37. Reservoir 2 energy inflow from heater
38. Reservoir 2 energy outflow
39. Reservoir 2 energy level
40. Reservoir 2 water target temperature
41. Window
42. Actions

Appendix C: Sample action-transition graph



Appendix D: Dxtract log file extraction program

It may be tedious to run the dxtract command for a large number of trials, the following UNIX shell program will run through a simple loop changing subject names, log file numbers, and executing the dxtract command line for each one. In the following example, the 42nd variable (Actions) will be extracted but this can be changed to suit one's needs:

```
for SUBJECT in [list of subjects separated by a space]
do
for LOG in [list of log file numbers separated by a space]
        do
                input = $SUBJECT.$LOG.log
                outputdx = $SUBJECT.$LOG.dx
                echo $input " ->      " $outputdx
                dxtract -42 $input $ouputdx
        done
done
```

Appendix E: List of commands

duress:

The DURESS II simulator. Usage:

% duress

dplayer:

Replays a session using the log file created with duress. Usage:

% dplayer

dxtract:

Extracts a particular variable from a log file. Usage

% dxtract *[-h] [-v var#]* infile *[outfile]*

dgraphgen:

Generates the action-transition graph of a session. Usage:

% dgraphgen graph#

dgraph:

Displays a graph generated by dgraphgen. Allows re-positioning of vertices and generation of PostScript files. Usage:

% dgraph *[graphfile]*

dloggen:

Creates a "complete" log file by interpolating the data obtained from a log file generated with DURESS II. Usage:

% dloggen interval infile outfile

combine:

Combines columns of data obtained with dxtract in a single file. Usage:

% combine file1 file2 ...

logfile.summary.macro:

Lists all trials where the simulation was stopped because steady state was reached or a system breakdown occurred. The data is listed in three columns. The first is the log file name; the second is the reason for termination; and the last is the total time elapsed for the trial. Usage:

% logfile.summary.macro

compress & uncompress:

Because some files (especially the log files) are very large, it is advisable to compress them. This will make file management much more efficient and save a considerable amount of disk space. Usage:

% compress *[file name]*

However, before a file can be used in programs such as dplayer, it must be uncompressed. Usage:

% uncompress *[file name]*

Note that compressed files will have the extension '.Z'

Cognitive Engineering Laboratory

CEL TECHNICAL REPORT SERIES

CEL 93-01 "Egg-sucking, Mousetraps, and the Tower of Babel: Making Human Factors Guidance More Accessible to Designers"
• Kim J. Vicente, Catherine M. Burns, & William S. Pawlak

CEL 93-02 "Effects of Expertise on Reasoning Trajectories in an Abstraction Hierarchy: Fault Diagnosis in a Process Control System"
• Klaus Christoffersen, Alex Pereklita, & Kim J. Vicente

CEL 94-01 "Cognitive 'Dipsticks': Knowledge Elicitation Techniques for Cognitive Engineering Research"
• Klaus Christoffersen, Christopher N. Hunter, & Kim J. Vicente

CEL 94-02 "Muddling Through Wicked Problems: Exploring the Role of Human Factors Information in Design"
• Catherine M. Burns

CEL 94-03 "Cognitive Work Analysis for the DURESS II System"
• Kim J. Vicente & William S. Pawlak

CEL 94-04 "Inducing Effective Control Strategies Through Ecological Interface Design"
• William S. Pawlak

CEL 94-05 "Research on Factors Influencing Human Cognitive Behaviour (I)"
• Klaus Christoffersen, Christopher N. Hunter, & Kim J. Vicente

CEL 94-06 "Ecological Interfaces for Complex Industrial Plants"
• Nick Dinadis & Kim J. Vicente

CEL 94-07 "Evaluation of a Display Design Space: Transparent Layered User Interfaces"
• Beverly L. Harrison, Hiroshi Ishii, Kim J. Vicente, & Bill Buxton

CEL 94-08 "Designing and Evaluating Semi-Transparent 'Silk' User Interface Objects:
Supporting Focused and Divided Attention"
• Beverly L. Harrison, Shumin Zhai, Kim J. Vicente, & Bill Buxton

CEL 95-01 "An Ecological Theory of Expertise Effects in Memory Recall"
• Kim J. Vicente & JoAnne H. Wang

CEL 95-02 "Strategic Plan - 1995"
• Cognitive Engineering Laboratory

CEL 95-03 "Cognitive Engineering Laboratory Profile"
• Cognitive Engineering Laboratory

CEL 95-04 "A Field Study of Operator Cognitive Monitoring at Pickering Nuclear Generating Station-B"
• Kim J. Vicente & Catherine M. Burns

CEL 95-05 "An Empirical Investigation of the Effects of Training and Interface Design on the Control of Complex Systems"
• Christopher N. Hunter

CEL 95-06 "Applying Human Factors to the Design of Medical Equipment: Patient-Controlled Analgesia"
• Laura Lin, Racquel Isla, Karine Doniz, Heather Harkness, Kim J. Vicente, & D. John Doyle

CEL 95-07 "An Experimental Evaluation of Transparent Menu Usage"
• Beverly L. Harrison & Kim J. Vicente

CEL 95-08 "Research on Factors Influencing Human Cognitive Behaviour (II)"
• Christopher N. Hunter, Michael E. Janzen, & Kim J. Vicente

CEL 95-09 "To the Beat of a Different Drummer: The Role of Individual Differences in Ecological Interface Design"
• Dianne Howie

CEL 95-10 "Emergent Features and Temporal Information: Shall the Twain Ever Meet?"
• JoAnne H. Wang

CEL 95-11 "Physical and Functional Displays in Process Supervision and Control"
• Catherine M. Burns & Kim J. Vicente

CEL 96-01 "Shaping Expertise Through Ecological Interface Design: Strategies, Metacognition, and Individual Differences"
• Dianne E. Howie

CEL 96-02 "Skill, Participation, and Competence: Implications of Ecological Interface Design for Working Life"
• Peter Benda, Giuseppe Cioffi, & Kim J. Vicente

CEL 96-03 "Practical Problem Solving in a Design Microworld: An Exploratory Study'
• Klaus Christoffersen

CEL 96-04 "Review of Alarm Systems for Nuclear Power Plants"
• Kim J. Vicente

CEL 96-05 "DURESS II User's Manual: A Thermal-hydraulic Process Simulator for Research and Teaching"
• Lisa C. Orchanian, Thomas P. Smahel, Dianne E. Howie, & Kim J. Vicente